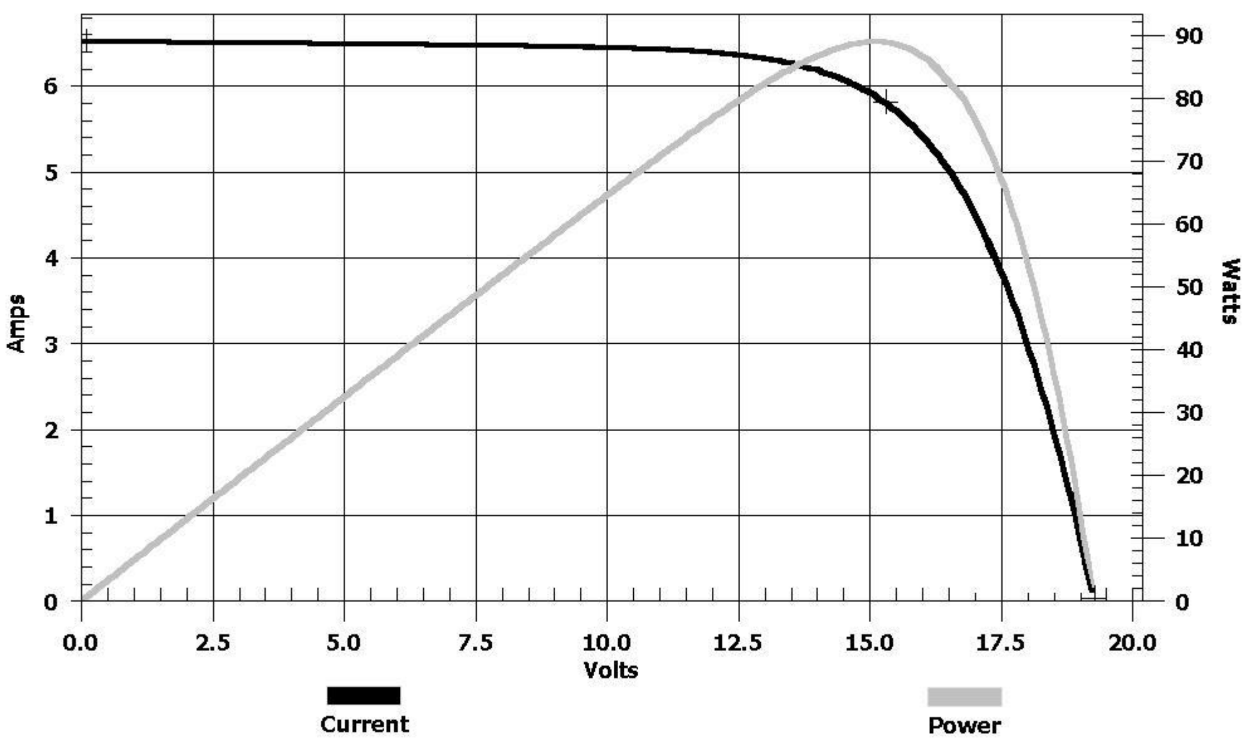
1. Explain briefly (6 p)

a) P-type doping of silicon
b) Minority carrier lifetime
c) Thin film solar cell
d) Effect of semiconductor band gap on the current and voltage of a pn-junction solar cell
e) Stand-alone photovoltaic system
f) Inverter

2. The figure below shows the current – voltage (IV) curve of a solar module (black curve) and corresponding power curves (power as the function of voltage, gray curve), measured at the standard test conditions (STC, radiation intensity 1000 W/m^2, temperature 25°C, AM1.5G spectrum). The dimensions of the module are 600 x 1000 mm. Estimate approximately from the graph the open circuit voltage (V_{OC}), short circuit current (I_{SC}), fill factor (FF), and energy conversion efficiency (η) of the module in the following cases a) and b)

a) The initial case, as shown in the figure (2 p),
b) Otherwise the same, but an additional shunt resistance (R_{SH}) of 10 Ω affects the performance of the module (2 p)
c) What is the operating point (current, voltage, power) when a load resistance of 5 Ω is connected to the solar module in case b)? (1 p)
d) What value of the load resistance would draw the maximum power from the solar cell in case b)? (1 p)



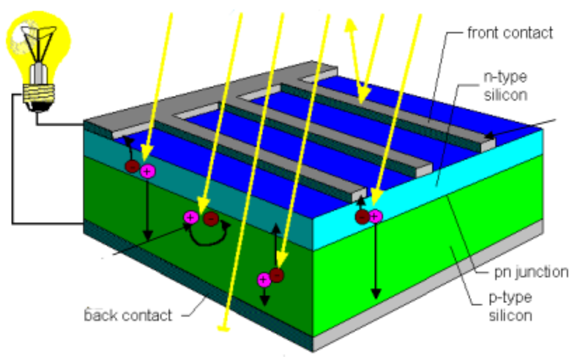
3. Let's consider how doping affects the position of Fermi level in a semiconductor.

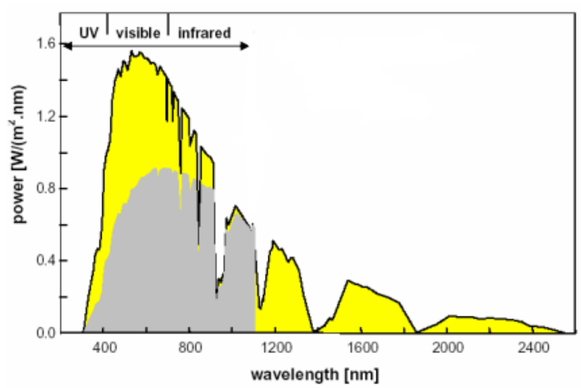
a) What is the energy difference between Fermi level and conduction band edge at room temperature, when the semiconductor, whose effective density of states in the conduction band is $N_C = 2.1 \cdot 10^{25}\ /m^3$, is doped with donors atoms at density $N_D = 7.6 \cdot 10^{21}/m^3$? (2 p)

b) What is the difference between the valence band edge and the Fermi level, if a semiconductor, whose effective density of states in valence band is $N_V = 1.6 \cdot 10^{25}/m^3$, is doped with acceptor atoms at density $N_A = 2.2 \cdot 10^{22}/m^3$? (2 p)

c) The energy of the donor states in silicon doped with phosphorus is 0.045 eV below the conduction band edge. Assuming that the difference between the Fermi level and the conduction band in the semiconductor in question is 0.20 eV, calculate the probability to find an electron in a given donor state at room temperature. (2 p)

4. What are the main performance losses that limit the maximum theoretical energy conversion efficiency of crystalline silicon solar cells below 33 % and that of practical record solar cells to ca. 26 %? Name and briefly explain these loss processes, and identify the key material properties that determine them. What are the two fundamental loss factors that already together limit the efficiency to ca. 45 %? The figures below are given as a hint. (6 p)





5. Let's consider a grid-connected PV system installed on the roof of a single family house in Southern Finland, where the average total cost of grid electricity is 0.10 €/kWh. The yearly total solar irradiation on the module surface has been estimated to be 900 kWh/m² per year. The efficiency of the PV modules is 17 % and their expected operational lifetime is 25 years. The household consumes 7300 kWh electricity per year (120 m² floor area, four persons, no electric heating). Neglecting the time value of money, and assuming that the household can sell their surplus PV electricity at the same price as they electricity from the grid (net metering on a yearly basis),

a) How low should the investment costs (€/m² of module area) of the PV system be, to make the generated PV electricity competitive with the grid electricity? (1 p)
b) What are the investment costs of this system per rated power (€/W_p)? (1 p)
c) How large roof area must be covered with the PV modules to generate as much PV electricity as the household consumes per year? (1 p)
d) What is the investment cost of this system (€)? (1 p)
e) How does the time value of money affect the cost of PV electricity produced? (1 p)
f) What other factors should a more precise economic calculation take into account? (1 p)